

# TABLE OF CONTENTS

<b>LIST OF TABLES</b> .....	T-6
-----------------------------	-----

<b>LIST OF FIGURES</b> .....	T-9
------------------------------	-----

## **EXECUTIVE SUMMARY**

INTRODUCTION .....	S-1
HYDROLOGY .....	S-1
GEOMORPHOLOGY .....	S-2
History of Fluvial Morphology .....	S-2
Geomorphological Reach Description .....	S-3
Channel Geometry .....	S-4
Cobble Bar Characterization .....	S-4
Flows to Support Cobble Transport .....	S-4
LOW VELOCITY HABITAT MAINTENANCE .....	S-5
SUSPENDED SEDIMENT ANALYSIS .....	S-6
HABITAT .....	S-6

## **CHAPTER 1: INTRODUCTION**

SAN JUAN RIVER STUDY AREA DESCRIPTION .....	1-2
HISTORICAL SETTING .....	1-6

## **CHAPTER 2: HYDROLOGY**

BACKGROUND .....	2-1
Pre-Navajo Dam (1929 to 1961) .....	2-1
Post-Dam Period (1962 to 1991) .....	2-4
OBJECTIVES .....	2-4
METHODS .....	2-4
RESULTS .....	2-6
Storm Influence .....	
Water Temperature .....	2-13
DISCUSSION .....	2-15
CONCLUSIONS .....	2-16

## **CHAPTER 3: GEOMORPHOLOGY**

BACKGROUND .....	3-1
OBJECTIVES .....	3-3
Historical Analysis of Fluvial Morphology .....	3-3
Geomorphological Characterization .....	3-3
Channel Geometry Analysis .....	3-3

Cobble Substrate Characterization . . . . .	3-3
Suspended Sediment Analysis . . . . .	3-4
METHODS . . . . .	3-4
Historic Analysis of Fluvial Morphology . . . . .	3-4
Geomorphological Characterization . . . . .	3-4
River Valley Geometry . . . . .	3-6
Channel Contact Geology . . . . .	3-6
Riparian Vegetation . . . . .	3-6
Channel Gradient . . . . .	3-8
Channel Pattern . . . . .	3-8
Tributary Influence . . . . .	3-9
Man's Influence . . . . .	3-9
Aquatic Habitat . . . . .	3-9
Identify River Reach . . . . .	3-9
Channel Geometry Analysis . . . . .	3-12
Cross-Section Measurement in Representative River	
Transects . . . . .	3-12
Channel Response to Flows at USGS Gage Locations . . . . .	3-13
Flow Modification Impact on Channel Complexity . . . . .	3-17
Bankfull Channel Capacity . . . . .	3-18
Cobble Bar Characterization . . . . .	3-19
Characterization of Bed Material in Suspected and Potential Spawning	
Bars . . . . .	3-19
Depth of Open Interstitial Space in Cobble Bars . . . . .	3-21
Topographic Changes in Cobble Bars . . . . .	3-22
Cobble Transport Analysis . . . . .	3-22
Low Velocity Habitat Creation and Maintenance . . . . .	3-22
Suspended Sediment Analysis . . . . .	3-23
Sediment Sampling . . . . .	3-23
Sediment Transport Analysis . . . . .	3-24
RESULTS . . . . .	3-26
Historic Analysis of Fluvial Morphology . . . . .	3-26
Geomorphological Characterization . . . . .	3-29
River Valley Geometry . . . . .	3-29
Channel Contact Geology . . . . .	3-29
Riparian Vegetation . . . . .	3-33
Channel Gradient . . . . .	3-36
Channel Pattern . . . . .	3-36
Other Parameters . . . . .	3-36
Identify River Reaches . . . . .	3-36
River Geometry Analysis . . . . .	3-41
Cross Section Measurement for RT Series Transects . . . . .	3-41
Cross Section Measurement for Mixer Transects . . . . .	3-51
Cross Section Measurement for Debris Field Transects . . . . .	3-55
Cross Section Measurement for Clay Hills Transects . . . . .	3-55

Channel Response to Flows at USGS Gage Locations . . . . .	3-59
Substrate Movement at Surveyed Cross-Sections . . . . .	3-61
Flow Modification Impact on Channel Complexity . . . . .	3-63
Bankfull Channel Capacity . . . . .	3-65
Cobble Bar Characterization . . . . .	3-67
Characterization of Bed Material Size in Suspected	
Spawning Bars . . . . .	3-68
Depth of Open Interstitial Space in Cobble Bars . . . . .	3-73
Topographic Changes in Cobble Bars . . . . .	3-73
Cobble Bar Survey Summary . . . . .	3-76
Cobble Transport Analysis . . . . .	3-77
Low Velocity Habitat Creation and Maintenance . . . . .	3-79
Cobble/Sand Bar Monitoring . . . . .	3-79
Maintenance of Secondary Channel Associated Backwaters . . . . .	3-83
Channel Morphology Response Summary . . . . .	3-87
Suspended Sediment Sampling . . . . .	3-89
Sampling Results . . . . .	3-89
DISCUSSION . . . . .	3-95
Historic Analysis of Fluvial Morphology . . . . .	3-95
Geomorphological Characterization . . . . .	3-96
River Geometry Analysis . . . . .	3-98
Cobble Bar Characterization . . . . .	3-100
Flows to Support Cobble Transport . . . . .	3-100
Low Velocity Habitat Maintenance - Measurement of Change in Sand/Cobble	
Bars . . . . .	3-102
Suspended Sediment Analysis . . . . .	3-103
CONCLUSIONS . . . . .	3-103
History of Fluvial Morphology . . . . .	3-103
Change in Channel Morphology with Test Flows . . . . .	3-103
Cobble Bar Characterization . . . . .	3-104
Low Velocity Habitat Creation and Maintenance . . . . .	3-104
Suspended Sediment Analysis . . . . .	3-104

## CHAPTER 4: HABITAT STUDIES

INTRODUCTION . . . . .	4-1
METHODS . . . . .	4-1
RESULTS . . . . .	4-4
DISCUSSION . . . . .	4-14
SUMMARY AND CONCLUSIONS . . . . .	4-21

## **CHAPTER 5: PHYSICAL HABITAT DESCRIPTIONS**

INTRODUCTION .....	5-1
METHODS .....	5-1
RESULTS .....	5-2
Mean Water Velocity .....	5-4
Depth .....	5-7
Depth to Embeddedness .....	5-9
Interstitial Sediment .....	5-12
Particles <0.063 mm .....	5-12
Particles >12.5 mm .....	5-15
Discriminant Functions Analysis .....	5-17
CONCLUSIONS .....	5-19

## **CHAPTER 6: MAINSTREAM HABITAT QUALITY**

INTRODUCTION .....	6-1
METHODS .....	6-1
Physical Parameters .....	6-2
Biological Parameters .....	6-3
RESULTS .....	6-3
Temporal Variations .....	6-4
Physical Parameters .....	6-4
Biological Parameters .....	6-7
Spatial Variations .....	6-15
Physical Parameters .....	6-15
Biological Parameters .....	6-15
DISCUSSION .....	6-19
SUMMARY AND CONCLUSIONS .....	6-24

## **CHAPTER 7: BACKWATER PRODUCTIVITY**

INTRODUCTION .....	7-1
STUDY AREA .....	7-2
METHODS .....	7-4
Water depth (m) .....	7-4
Total Suspended Solids (mg/L) .....	7-4
Temperature (°C) .....	7-4
Dissolved oxygen (mg/L) .....	7-5
Phytoplankton (µg/L) .....	7-5
Zooplankton (#/m <sup>3</sup> ) .....	7-5
Periphyton (mg/m <sup>2</sup> ) .....	7-5
Benthic invertebrates (g/m <sup>2</sup> ) .....	7-5
Detritus (g/m <sup>2</sup> ) .....	7-5
Sediment (% dry wt.) .....	7-6
RESULTS .....	7-6
Hydrology .....	7-6

San Juan River	7-6
Colorado and Green Rivers	7-8
Backwater Quality/Productivity	7-8
Water Depth	7-8
Total Suspended Solids	7-13
Temperature	7-16
Dissolved Oxygen	7-19
Phytoplankton	7-21
Zooplankton	7-21
Periphyton	7-26
Benthic Invertebrates	7-34
Detritus	7-36
DISCUSSION	7-42
SUMMARY AND CONCLUSIONS	7-45

## REFERENCES

### APPENDIX A: Cobble Bar Surface Plots

Figure A.1.	Surface plots of cobble bar at RM 173.7 (1996-1998)	A-1
Figure A.2.	April 2, 1996 survey with embeddedness markers	A-2
Figure A.3.	July 8, 1996 survey with embeddedness markers	A-2
Figure A.4.	August 22, 1997 survey with embeddedness markers	A-3
Figure A.5.	August 10, 1998 survey with embeddedness markers	A-3
Figure A.6.	Image shows positive and negative changes between April 2, 1996 and July 8, 1996	A-4
Figure A.7.	Image shows positive changes with the zero datum as a grey planar surface	A-4
Figure A.8.	Image shows positive and negative changes between July 8, 1996 and August 22, 1997	A-5
Figure A.9.	Image shows positive and negative changes between August 22, 1997 and August 10, 1998	A-5
Figure A.10.	Surface plots of cobble bar at RM 168.4	A-6
Figure A.11.	April 3, 1996 survey with embeddedness markers	A-7
Figure A.12.	July 9, 1996 survey with embeddedness markers	A-7
Figure A.13.	August 22, 1997 survey with embeddedness markers	A-8
Figure A.14.	July 29, 1998 survey with embeddedness markers	A-8
Figure A.15.	Areas of Deposition and Scour between April 3, 1996 and July 9, 1996	A-9
Figure A.16.	Areas of Deposition and Scour between July 9, 1996 and August 22, 1997	A-9
Figure A.17.	Areas of Deposition and Scour between August 22, 1997 and July 29, 1998	A-10
Figure A.18.	Surface plots of cobble bar at RM 132 (1995-1998)	A11
Figure A.19.	March 8, 1995 survey (no embeddedness data taken)	A-12

Figure A.20.	July 25, 1995 survey with embeddedness markers . . . . .	A-12
Figure A.21.	March 13, 1996 survey (no embeddedness data taken . . . . .	A-13
Figure A.22.	July 10, 1996 survey with embeddedness markers . . . . .	A-13
Figure A.23.	August 21, 1997 survey with embeddedness markers . . . . .	A-14
Figure A.24.	August 11, 1998 survey with embeddedness markers . . . . .	A-14
Figure A.25.	Areas of Deposition and Scour between July 25, 1995 and July 10, 1996 . . . . .	A-15
Figure A.26.	Areas of Deposition and Scour between July 10, 1996 and August 21, 1997 . . . . .	A-15
Figure A.27.	Areas of Deposition and Scour between August 21, 1997 and August 11, 1998 . . . . .	A-16

## **APPENDIX B: Low velocity Habitat Sand/Cobble Bar Surface Plots**

Figure B.1.	Location photo of Bar D-4 at RM 86.4 . . . . .	B-1
Figure B.2.	Surface plots of D-1 Cobble Bar, August 24, 1994 - October 8, 1996 . . . . .	B-2
Figure B.3.	Location photo of Bar D-4 at RM 86.4 . . . . .	B-3
Figure B.4.	Surface plots of D-4 cobble bar, August 24, 1994 - October 8, 1996 . . . . .	B-4
Figure B.5.	Location photo of C-2 bar (RM 4) . . . . .	B-5
Figure B.6.	Surface plots of C-2 cobble bar, August 25, 1994 - October 9, 1996 . . . . .	B-6

## **APPENDIX C: Statistical Tables**

Summary Statistics: All Habitats by Strata . . . . .	C-1
Summary Statistics: Riffle Habitats by Strata . . . . .	C-4
Summary Statistics: Run Habitats by Strata . . . . .	C-7
Summary Statistics: All Habitats by Trip . . . . .	C-11
Summary Statistics: Riffle Habitats by Trip . . . . .	C-14
Summary Statistics: Run Habitats by Trip . . . . .	C-17

## LIST OF TABLES

Table 2.1.	Comparison of storm magnitude and frequency for the Colorado River at Cisco gage, Green River at Green River gage, and San Juan River near Bluff gage, 1929-1961 . . . . .	2-3
Table 2.2.	Water temperature monitoring locations and period of record. . . . .	2-5
Table 2.3.	Summary of Navajo Dam release hydrograph characteristics during the research period, 1992 to 1998. . . . .	2-7
Table 2.4.	Anticipated and Actual flow conditions achieved in the San Juan River below Farmington as a result of designed releases at Navajo Dam. . . .	2-8
Table 2.5.	Summary of research flows for the research period, San Juan River at Four Corners, New Mexico. . . . .	2-10
Table 2.6.	Summary of research flows for the pre-dam and research periods, San Juan River near Bluff, Utah. . . . .	2-11
Table 2.7.	Comparison of hydrograph statistics for pre-dam (1929-1961), post-dam (1962-1991) and research period (1992-1998) for the San Juan River near Bluff, Utah. . . . .	2-12
Table 3.1.	Aerial photography coverage by river mile used in the historical analysis for the periods 1935-1937, 1950-1952, 1959-1962, and 1986-1988. . . . .	3-5
Table 3.2.	Stream channel contact geology descriptions used in mapping. . . . .	3-7
Table 3.3.	Vegetation types and codes used in mapping riparian vegetation. . . . .	3-7
Table 3.4.	Data sets used in channel reach definition analysis. . . . .	3-10
Table 3.5.	Location descriptions of general reaches in San Juan River having different characteristics. . . . .	3-11
Table 3.6.	Transect survey locations and summary of completed surveys . . . . .	3-17
Table 3.7.	Cobble bar sampling locations . . . . .	3-20
Table 3.8.	Sand/cobble bar survey locations and dates . . . . .	3-23
Table 3.9.	Sediment sample locations and number of samples taken each year .	3-25
Table 3.10.	Summary of historic aerial photography analysis of changes in channel morphology of the San Juan River from four periods, 1934-35, 1950-52, 1959-62 and 1986-88 . . . . .	3-27
Table 3.11.	Relative abundance of vegetation by type . . . . .	3-35
Table 3.12.	Reach definitions, variables considered and their mean values within reach utilized in delivering geomorphologically different reaches . . . . .	3-38
Table 3.13.	Frequency two-way table categorized by assigned and predicted reaches . . . . .	3-40
Table 3.14.	Summary of RT-series transect changes with time. . . . .	3-45
Table 3.15.	Discharge at Four Corners and elevation change data for RT cross-sections. . . . .	3-46
Table 3.16.	Results of regression analysis of channel change (scour or deposition) during runoff at RT cross-sections vs runoff and change during previous non-runoff period . . . . .	3-47

Table 3.17.	Percent cobble substrate for the RT series transects on the San Juan River (1992-1998). . . . .	3-50
Table 3.18.	Summary of Mixer series transect changes with time. . . . .	3-53
Table 3.19.	Percent cobble substrate for the Mixer series transects on the San Juan River (1993-1998). . . . .	3-54
Table 3.20.	Summary of debris field series transect changes with time. . . . .	3-57
Table 3.21.	Percent cobble substrate for the debris field series transects on the San Juan River (1993-1998). . . . .	3-57
Table 3.22.	Average deposition and scour (total and cobble) at RT and Mixer series transects in the San Juan River (1992-1998) as related to hydrographic conditions. . . . .	3-62
Table 3.23.	Bankfull discharge from HEC-RAS modeling of four 0.25 mile (mi) reaches in the San Juan River between River Mile (RM) 133 and RM 174 . . .	3-67
Table 3.24.	Cobble size distribution for potential spawning sites from 1995 survey . . . . .	3-69
Table 3.25.	Size distribution of interstitial material at selected cobble bars from 1995 survey . . . . .	3-70
Table 3.26.	Cobble size distribution for two suspected and two potential spawning bars in the San Juan River, 1995-1998. . . . .	3-71
Table 3.27.	Summary of cobble, open interstitial space and interstitial material for potential spawning bars in the San Juan River surveyed in 1995. . . .	3-74
Table 3.28.	Summary of depth of open interstitial space in cobble bars. . . . .	3-75
Table 3.29.	Summary of changes in three cobble bars in the San Juan River surveyed between 1995 and 1998. (needs to be converted to metric) . . . . .	3-76
Table 3.30.	Boundary shear stress conditions at various flow rates for four modeled reaches. . . . .	3-77
Table 3.31.	Flows required to meet critical shear stress conditions for cobble transport. . . . .	3-78
Table 3.32.	D-1 Bar Survey Summary. . . . .	3-80
Table 3.33.	D-4 Bar Survey Summary. . . . .	3-81
Table 3.34.	CH-2 Bar Survey Summary. . . . .	3-82
Table 3.35.	Sediment concentrations (parts per million (ppm)) used in HEC-6 simulations. . . . .	3-84
Table 3.36.	Summary of HEC-6 modeling results for Montezuma Creek site. . . .	3-87
Table 4.1.	The Hydrologic Characteristics of Each Mapping Run by Geomorphic Reach . . . . .	4-2
Table 4.2.	The Detailed Habitat Types and the Eight General Categories on the San Juan River . . . . .	4-3
Table 4.3.	A Comparison of Significant Correlations (P#0.05) Between the Hydrologic Parameters Investigated for Antecedent Conditions Relative to Backwater Surface Areas . . . . .	4-15
Table 4.4.	the Coefficient of Determination Expressed as $r^2$ and Their Associated p Values for Backwater Habitat Area Normalized to 1000 Cfs Compared to Various Antecedent Hydrologic Conditions . . . . .	4-17



Table 5.1.	Mean Water Column Velocity (cm/sec) Statistics for Eight Habitat Types in Section 2 for November, 1994, to September, 1995 . . . . .	5-5
Table 5.2.	Water Depth (m) Statistics for Eight Habitat Types in Section 2 for November, 1994, to September, 1995 . . . . .	5-8
Table 5.3.	Depth to Embeddedness (cm) Statistics for Eight Habitat Types in Section 2 for November, 1994, to September, 1995 . . . . .	5-10
Table 5.4	The Results of Discriminant Analysis Performed on Mean Column Velocity, Depth, DTE, and Substrate Larger than >12.5 mm Data Collected from Eight Habitat Types in the San Juan River . . . . .	5-18
Table 5.5	Old and Revised Habitat Definitions for Eight Habitat Types in the San Juan River . . . . .	5-20
Table 6.1	A Summary of the Number of Riffle and Run Habitats Sampled by Date and Geomorphic Reach in the San Juan River . . . . .	6-2
Table 6.2	Physical and Biological Parameters Collected Within Each Sample Reach for Selected Run and Riffle . . . . .	6-2
Table 6.3	A Summary of the 1994, 1995, and 1996 Runoff Hydrograph and Subsequent Monsoon Periods Prior to Each Sample Date (Data from Four-Corners, NM) . . . . .	6-4
Table 6.4	The comparison between pre- and post-runoff samples for each physical and biological parameter measured in the San Juan River . . . . .	6-14
Table 7.1	The number of backwaters sampled per geomorphic reach from 1995 through 1997 by dated and numbered sampling period. Mean discharge (Q) during each trip as measured at Four Corners, New Mexico (USGS no. 09371010) is also indicated . . . . .	7-3

## LIST OF FIGURES

Figure 1.1.	San Juan Basin Location Map . . . . .	1-3
Figure 2.1.	San Juan River near Bluff, Utah, average hydrographs for pre-dam, post-dam and 1992-1998 study period. . . . .	2-2
Figure 2.2.	Hydrographs for the San Juan River at Four Corners for 1991 - 1994 . . . . .	2-8
Figure 2.3.	Hydrographs for the San Juan River at Four Corners for 1995 - 1998 . . . . .	2-8
Figure 2.4.	Frequency distribution of storm-event days for the San Juan River at Farmington, New Mexico and near Bluff, Utah, 1931-1998. . . . .	2-14
Figure 2.5.	Seven-day running mean daily water temperature for the San Juan River at Archuleta, New Mexico, and at Shiprock, New Mexico during pre-dam, post-dam and research flow periods. . . . .	2-14
Figure 3.1.	San Juan River Gradient . . . . .	3-2
Figure 3.2.	San Juan River Transect Locations in the "Mixer" Detail Reach . . . . .	3-14
Figure 3.3.	San Juan River Transect Locations in the "Debris Field", RM 83 to RM 88 . . . . .	3-15
Figure 3.4.	San Juan River Transect Locations, RM 0 to RM 14 . . . . .	3-16
Figure 3.5.	Aerial photograph of the San Juan River between RM 84 and RM86 taken in 1934. . . . .	3-30
Figure 3.6.	Aerial photograph of the San Juan River between RM 84 and RM86 taken in 1952. . . . .	3-30
Figure 3.7.	Aerial photograph of the San Juan River between RM 84 and RM86 taken in 1961. . . . .	3-31
Figure 3.8.	Aerial photograph of the San Juan River between RM 84 and RM86 taken in 1988. . . . .	3-31
Figure 3.9.	Valley Width by River Mile for the San Juan River . . . . .	3-32
Figure 3.10.	Three-Mile Running Average Channel Contact Geology (cutbank or bedrock) for the San Juan River. . . . .	3-32
Figure 3.11.	Main Channel Riparian Vegetation Area per River Mile for the San Juan River (3 mile running average). . . . .	3-34
Figure 3.12.	Relative Composition of Riparian Vegetation for the San Juan River (3 mile running average). . . . .	3-35
Figure 3.13.	Three-Mile Running Average Channel Gradient for the San Juan River. . . . .	3-37
Figure 3.14.	Three-Mile Running Average Channel Sinuosity for the San Juan River . . . . .	3-37
Figure 3.15.	Distribution of Normalized Key Parameters used in Reach Definition . . . . .	3-42
Figure 3.16.	1992-1998 Relative bed elevation for each of the RT transects on the San Juan River . . . . .	3-44

Figure 3.17.	1992 - 1998 Average relative bed elevation for RT series transects, on the San Juan River	3-44
Figure 3.18.	Predicted vs measured channel change in response to runoff for all RT transects in the San Juan River (1993-1997).	3-48
Figure 3.19.	Relative bed elevation for all Mixer series transects on the San Juan River (1993 - 1998).	3-52
Figure 3.20.	Average relative bed elevation for Mixer series transects (M-3 to M-8) on the San Juan River (1993-1998).	3-52
Figure 3.21.	Relative bed elevation for all Debris Field series transects on the San Juan River (1993 - 1998).	3-56
Figure 3.22.	Average relative bed elevation for Debris Field series transects on the San Juan River (1993-1998)	3-56
Figure 3.23.	Relative bed elevation for the two Clay Hills series transects on the San Juan River (1993 - 1998).	3-58
Figure 3.24.	Average relative bed elevation for Clay Hills series transects on the San Juan River (1993-1998).	3-58
Figure 3.25.	Lake Powell water surface elevation (1986-1998).	3-59
Figure 3.26.	Mean relative bed elevation at the San Juan River at Farmington gage (1942-1996)	3-60
Figure 3.27.	Mean relative bed elevation at the San Juan River at Shiprock gage (1943-1996)	3-60
Figure 3.28.	Relationship between main channel flow and island count.	3-63
Figure 3.29.	Island count in Reaches 3, 4, and 5 at base flow vs. time as a measure of change in channel complexity	3-64
Figure 3.30.	Habitat Diversity and Island Count in the San Juan River at flows below 1,200 cfs, 1992-1997.	3-66
Figure 3.31.	Cobble size frequency distribution for ruler and template measured cobble samples	3-72
Figure 3.32.	Comparison of cobble size measured with ruler and template and the resulting regression line	3-72
Figure 3.33.	Flow and backwater depths for 1997 runoff for the Montezuma Creek and Sand Island sites	3-84
Figure 3.34.	HEC-6 calibration results for Sand Island and Montezuma Creek	3-85
Figure 3.35.	Modeling results with small change in grain size to demonstrate sensitivity	3-85
Figure 3.36.	Suspended sediment vs flow for the San Juan River at Farmington, 1992-1998.	3-90
Figure 3.37.	Suspended sediment vs flow for the San Juan River at Shiprock, 1992-1998	3-90
Figure 3.38.	Suspended sediment vs flow for the San Juan River at Four Corners, 1992-1998.	3-91
Figure 3.39.	Suspended sediment vs flow for the San Juan River at Montezuma Creek, 1992-1998.	3-91
Figure 3.40.	Suspended sediment vs flow for the San Juan River at Bluff, 1960-83 compared to 1992-1998.	3-92

Figure 3.41.	Suspended sediment vs flow for the San Juan River at Four Corners, 1992-1998, for non-storm influenced samples. . . . .	3-93
Figure 3.42.	Suspended sediment vs flow for the San Juan River at Montezuma Creek 1992-1998, for non-storm influenced samples. . . . .	3-93
Figure 3.43.	Daily flow and spot suspended sediment concentration for the San Juan River at Four Corners, 1994 - 1998. . . . .	3-94
Figure 4.1	The Spatial Distribution of the Seven Major Habitat Types (Excluding "Other") in the San Juan River for Three Flow Regimes . . . . .	4-5
Figure 4.2	The Spatial Distribution of Seven Habitat Categories in the San Juan River with Expanded Scales to Allow Viewing Minor Categories . . . . .	4-6
Figure 4.3	The Total Wetted Area vs. Flow Relationships for the Three Combinations of Geomorphic Reaches . . . . .	4-7
Figure 4.4	A Summary of the Major Habitat Categories as a Percent of Total Wetted Area for a High, Medium and Low Flow Period . . . . .	4-8
Figure 4.5	The Comparison Between Habitat Area (M2) and Mapping Flow for the Sum of Reaches 1 Through 6 in the San Juan River for Runs (above) and Inundated Vegetation (below) . . . . .	4-9
Figure 4.6	The Comparison Between Habitat Area (m2) and Mapping Flow for the Sum of Reaches 1 Through 6 in the San Juan River for Shoal Types (above) and Riffles (below) . . . . .	4-10
Figure 4.7	The Comparison Between Habitat Area (m2) and Mapping Flow for the Sum of Reaches 1 Through 6 in the San Juan River for Pools (above) and Eddies (below) . . . . .	4-11
Figure 4.8	The Comparison Between Habitat Area (m2) and Mapping Flow for the Sum of Reaches 1 Through 6 in the San Juan River for Slackwaters . . . . .	4-12
Figure 4.9	The Relationship Between Backwater Surface Area and Flow for Reaches 1 and 2 Based upon Location Within the Channel . . . . .	4-12
Figure 4.10	The Relationship Between Backwater Surface Area and Flow for Reaches 3, 4, 5 and 6 in the San Juan River . . . . .	4-13
Figure 4.11	Flow/backwater Habitat Area Relationships for Reach 3 . . . . .	4-19
Figure 4.12	Flow/backwater Habitat Model for Reaches 1 to 4 and 1 to 5 Based on Flushed and Nonflushed Conditions . . . . .	4-20
Figure 5.1.	San Juan River Mean Daily Discharge over Study Period as Measured at Four Corners, New Mexico Gaging Station. Vertical Bars Indicate Habitat Sampling Trips.	
Figure 5.2	Mean ( $\pm$ 1 SE) Water Velocity for Eight Habitat Types in the San Juan River . . . . .	5-5
Figure 5.3	Mean ( $\pm$ 1 SE) Water Velocity for Eight Habitat Types in the San Juan River by Section During September, 1995 . . . . .	5-6
Figure 5.4.	Mean ( $\pm$ 1 SE) Depth for Eight Habitat Types in the San Juan River . . . . .	5-7

Figure 5.5.	Mean ( $\pm 1$ SE) Depth for Eight Habitat Types in the San Juan River by Section During September, 1995 . . . . .	5-8
Figure 5.6.	Mean ( $\pm 1$ SE) Depth to Embeddedness for Eight Habitat Types in the San Juan River . . . . .	5-9
Figure 5.7.	Mean ( $\pm 1$ SE) Depth to Embeddedness for Eight Habitat Types in the San Juan River by Section During September, 1995 . . . . .	5-10
Figure 5.8.	Mean ( $\pm 1$ SE) Depth to Embeddedness for Eight Habitat Types in the San Juan River in Section 2 During Four periods from November, 1994 to September, 1995 . . . . .	5-11
Figure 5.9.	Mean ( $\pm 1$ SE) Percentage (100% at 0-1 scale) of Sediment <0.063 mm for Eight Habitat Types in the San Juan River . . . . .	5-13
Figure 5.10.	Mean ( $\pm 1$ SE) Percentage (100% at 0-1 scale) of Sediment <0.063 mm for Eight Habitat Types in the San Juan River by Section During September, 1995 . . . . .	5-13
Figure 5.11.	Mean ( $\pm 1$ SE) Percentage (100% at 0-1 scale) of Sediment <0.063 mm for Riffle, Riffle-run, Run, and Cobble Shoals in the San Juan River in Section 2 . . . . .	5-14
Figure 5.12.	Mean ( $\pm 1$ SE) Percentage (100% at 0-1 scale) of Sediment <0.063 mm for Eddies, Slackwaters, Pools, and Backwaters in the San Juan River in Section 2 . . . . .	5-14
Figure 5.13.	Mean ( $\pm 1$ SE) Percentage (100% at 0-1 scale) of Sediment >12.5 mm for Eight Habitat Types in the San Juan River . . . . .	5-15
Figure 5.14.	Mean ( $\pm 1$ SE) Percentage (100% at 0-1 scale) of Sediment >12.5 mm for Eight Habitat Types in the San Juan River by Section During September, 1995 . . . . .	5-16
Figure 5.15.	Mean ( $\pm 1$ SE) Percentage (100% at 0-1 scale) of Sediment <0.063 mm for Riffle, Riffle-run, Run, and Cobble Shoals in the San Juan River in Section 2 During Four Periods from November, 1994 to September, 1995 . . . . .	5-16
Figure 5.16.	Plot of Primary Functions Derived from Discriminant Functions Analysis for Eight Habitat Types in the San Juan River . . . . .	5-18
Figure 6.1	The 1994 to 1997 Hydrograph at Four Corners, NM for the San Juan River. Habitat Quality Sample Periods Are Shown as Dark Columns on the Hydrograph . . . . .	6-5
Figure 6.2	The Temporal Distribution of the Substrate $D_{50}$ Values for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-6
Figure 6.3	The Temporal Distribution of the Depth of Embedded Layer (DTE) for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-8
Figure 6.4	The Temporal Distribution of the Percent Surface Area Embedded (PAE) for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-9
Figure 6.5	The Temporal Distribution of the Biomass of Periphyton (gms chla/m <sup>2</sup> ) for	

	Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-10
Figure 6.6	The Temporal Distribution of the Benthic Detritus (gms cpom/ m <sup>2</sup> ) for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-12
Figure 6.7	The Temporal Distribution of the Benthic Invertebrate Biomass (gm/m <sup>2</sup> ) for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-13
Figure 6.8	The Spatial Distribution of the D <sub>50</sub> for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-16
Figure 6.9.	The Spatial Distribution of the Percent Surface Area Embedded for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-17
Figure 6.10	The Spatial Distribution of the Depth to Embedded Layer for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-18
Figure 6.11	The Spatial Distribution of Periphyton Biomass (gms chla/m <sup>2</sup> ) for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-20
Figure 6.12	The Spatial Distribution of Benthic Detritus (gm/m <sup>2</sup> ) for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-21
Figure 6.13	The Spatial Distribution of Benthic Invertebrates (gm/m <sup>2</sup> ) for Each Trip Date for All Habitats Combined (above) and for Each Habitat Type (below) for the San Juan River . . . . .	6-22
Figure 6.14	The comparison for physical (above) and biological (lower) trophic parameters collected on the San Juan and Colorado River during 1994, 1995, and 1996. Within each river, the lowest geomorphic reach is on the left, with movement upstream toward the right. The San Juan has eight reaches, while the Colorado has eleven. . . . .	6-23
Figure 6.15	the Overall Averages of Physical (above) and Biological (lower) Benthic Parameters Collected in Riffles and Runs in the San Juan and Colorado Rivers . . . . .	6-25
Figure 7.1.	San Juan River Mean Daily Discharge for the 1995-97 Period as Measured at the Four Corners, New Mexico Gauge with the Timing and Numbering of Backwater Sampling Trips Indicated . . . . .	7-7
Figure 7.2.	Colorado River and Green River Mean Daily Discharge for the 1995-97 Period as Measured at the Cisco, Utah, and Green River, Utah Gauges with the Timing and Numbering of Backwater Sampling Trips Indicated . . . . .	7-9
Figure 7.3.	Mean Water Depth (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip . . . . .	7-10
Figure 7.4.	Mean Water Depth (±1 SE) in San Juan River Backwaters over the 1995-	

	97 Period by Geomorphic Reach . . . . .	7-11
Figure 7.5.	Mean Water Depth ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 Through 12 . . . . .	7-12
Figure 7.6.	Mean Water Depth ( $\pm 1$ SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12 . . . . .	7-12
Figure 7.7.	Mean Total Suspended Solids ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip . . . . .	7-13
Figure 7.8.	The Relationship Between Discharge and Total Suspended Solids in San Juan River Backwaters over the 1995-97 Period for Trips 1 through 12 . . . . .	7-14
Figure 7.9.	Mean Total Suspended Solids ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach. . . . .	7-15
Figure 7.10.	Mean Total Suspended Solids ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 through 11 . . . . .	7-15
Figure 7.11.	Mean Total Suspended Solids ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip . . . . .	7-16
Figure 7.12.	Mean Temperature ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip . . . . .	7-17
Figure 7.13.	Mean Temperature ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach . . . . .	7-17
Figure 7.14.	Mean Temperature ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip . . . . .	7-18
Figure 7.15.	Mean Temperature ( $\pm 1$ SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12 . . . . .	7-18
Figure 7.16.	Mean Dissolved Oxygen ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip . . . . .	7-19
Figure 7.17.	Mean Dissolved Oxygen ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip . . . . .	7-20
Figure 7.18.	Mean Dissolved Oxygen ( $\pm 1$ SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12. . . . .	7-20
Figure 7.19.	Mean Phytoplankton Biomass ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip . . . . .	7-21
Figure 7.20.	Mean Phytoplankton Biomass ( $\pm 1$ SE) in San Juan River Backwater at Rm 153 in Reach 5 by Sampling Trip . . . . .	7-22
Figure 7.21.	Mean Phytoplankton Biomass ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach . . . . .	7-23
Figure 7.22.	Mean Phytoplankton Biomass ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 through 12 . . . . .	7-23
Figure 7.24.	Mean Phytoplankton Biomass ( $\pm 1$ SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips	

9 through 12 . . . . .	7-24
Figure 7.23. Mean Phytoplankton Biomass ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip . . . . .	7-24
Figure 7.25. Mean Zooplankton Biomass ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip . . . . .	7-25
Figure 7.27. Mean Zooplankton Biomass ( $\pm 1$ SE) in San Juan River Backwaters During Trip 1 in August, 1995 by Geomorphic Reach . . . . .	7-27
Figure 7.26. Mean Zooplankton Biomass ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach . . . . .	7-27
Figure 7.28. Mean Zooplankton Biomass ( $\pm 1$ SE) in San Juan River Backwaters During Trip 2 in September, 1995 by Geomorphic Reach . . . . .	7-28
Figure 7.29. Mean Zooplankton Biomass ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 Through 11 . . . . .	7-28
Figure 7.30. Mean Zooplankton Biomass ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip . . . . .	7-29
Figure 7.31. Mean Zooplankton Biomass ( $\pm 1$ SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12 . . . . .	7-29
Figure 7.32. Mean Periphyton Biomass ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip . . . . .	7-30
Figure 7.33. Mean Periphyton Biomass ( $\pm 1$ SE) in San Juan River Backwaters During Trip 1 in August, 1995 by Geomorphic Reach . . . . .	7-30
Figure 7.34. Mean Periphyton Biomass ( $\pm 1$ SE) in San Juan River Backwaters During Trip 4 in April, 1996 by Geomorphic Reach . . . . .	7-32
Figure 7.35. Mean Periphyton Biomass ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 Through 12 . . . . .	7-32
Figure 7.36. Mean Periphyton Biomass ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip . . . . .	7-33
Figure 7.37. Mean Periphyton Biomass ( $\pm 1$ SE) in San Juan, Colorado, and Green River backwaters over the April- October 1997 Period for Sampling Trips 9 through 12 . . . . .	7-34
Figure 7.38. Mean Benthic Invertebrate Biomass ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip . . . . .	7-35
Figure 7.39. Mean Benthic Invertebrate Biomass ( $\pm 1$ SE) in San Juan River Backwaters During Trips 1 through 4 by Geomorphic Reach . . . . .	7-35
Figure 7.40. Mean Benthic Invertebrate Biomass ( $\pm 1$ SE) in San Juan River Backwaters During Trip 7 in December, 1996 by Geomorphic Reach . . . . .	7-37
Figure 7.41. Mean Benthic Invertebrate Biomass ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach . . . . .	7-37
Figure 7.43. Mean Benthic Invertebrate Biomass ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip . . . . .	7-38
Figure 7.42. Mean Benthic Invertebrate Biomass ( $\pm 1$ SE) in San Juan and Colorado	



	River Backwaters over the 1996-97 Period for Sampling Trips 5 Through 12 .....	7-38
Figure 7.44.	Mean Benthic Invertebrate Biomass ( $\pm 1$ SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12 .....	7-39
Figure 7.45.	Mean Detrital Biomass ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip .....	7-39
Figure 7.46.	Mean Detrital Biomass ( $\pm 1$ SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach .....	7-40
Figure 7.47.	Mean Detrital Biomass ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 through 12 .....	7-40
Figure 7.48.	Mean Detrital Biomass ( $\pm 1$ SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip .....	7-41
Figure 7.49.	Mean Detrital Biomass ( $\pm 1$ SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12 .....	7-41
Figure 7.50.	Mean Percentage ( $\pm 1$ SE) Dry Weight of Sediment <0.063 mm in San Juan River Backwaters over the 1995-97 Period by Trip .....	7-43
Figure 7.51.	Mean Percentage ( $\pm 1$ SE) Dry Weight of Sediment <0.063 mm in San Juan River Backwaters over the Period of August, 1995 to July, 1996 During Trips 1 through 5 by Geomorphic Reach .....	7-43